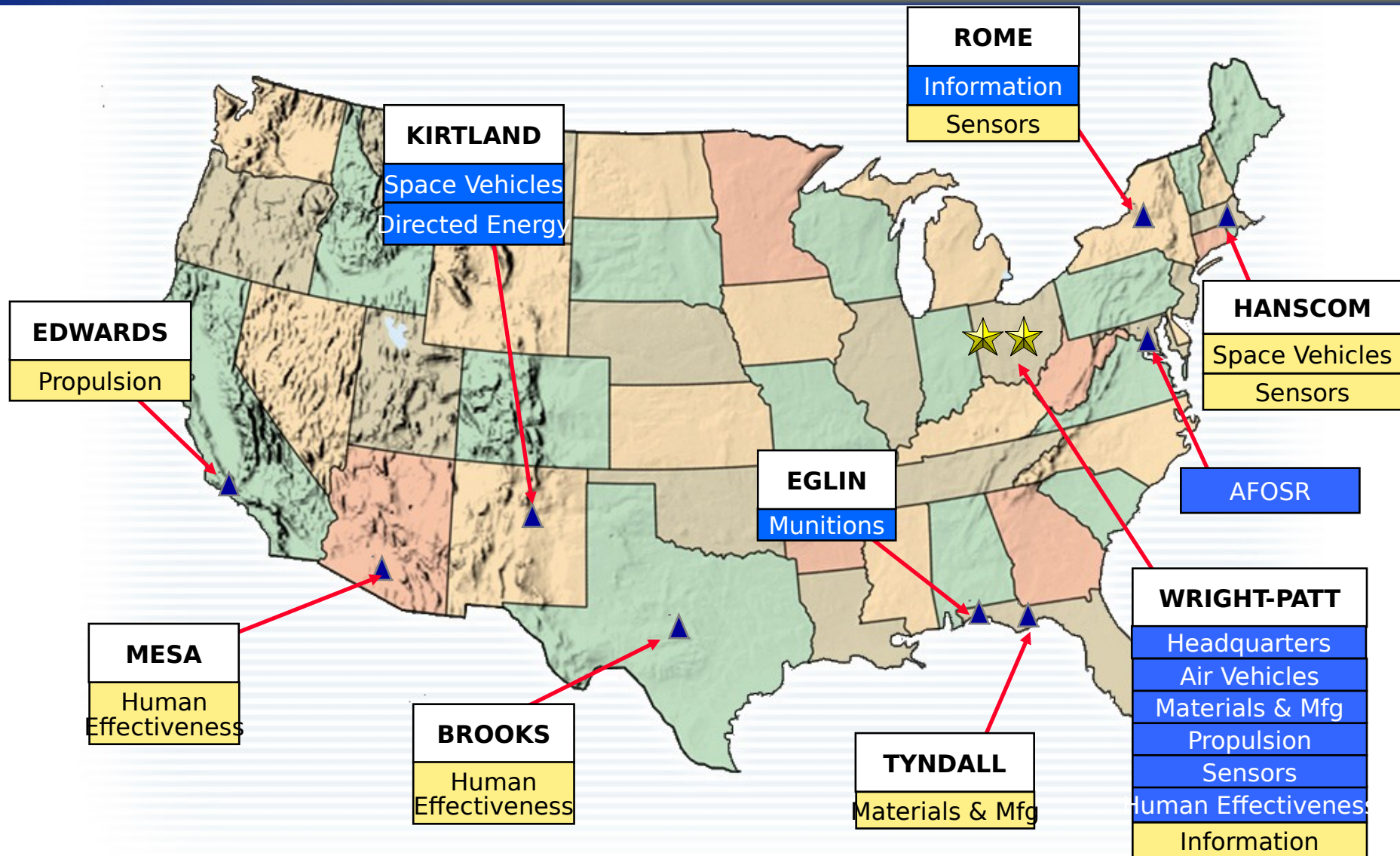AIR FORCE RESEARCH LABORATORY

AFRL Information Directorate

Dr. Northrup Fowler III

Chief Scientist, Acting

Information Directorate

Air Force Research Laboratory

Rome Research Site, NY

AFRL Sites

ROME
- Information
- Sensors

KIRTLAND
- Space Vehicles
- Directed Energy

HANSCOM
- Space Vehicles
- Sensors

EDWARDS
- Propulsion

AFOSR

EGLIN
- Munitions

MESA
- Human Effectiveness

BROOKS
- Human Effectiveness

TYNDALL
- Materials & Mfg

WRIGHT-PATT
- Headquarters
- Air Vehicles
- Materials & Mfg
- Propulsion
- Sensors
- Human Effectiveness
- Information

Information Directorate Mission

The advancement and application of Information Systems Science and Technology to meet Air Force unique requirements for Information Dominance and its transition to air and space systems to meet warfighter needs.

The Air Force Vision: Battlespace Dominance through Information Superiority

"The area with the greatest potential payoff... is in *C4ISR*... [to] ensure our commanders have the *best information for rapid battlefield decision-making*"

Gen Richard B. Meyers, CJCS, SASC testimony, 5 Feb 02

"Command and control systems—*based on information and communications technology*—and precision-guided munitions are critical to all stages of the Pentagon's efforts to transform itself to deal with 21st century threats."

Paul Wolfowitz, DSECDEF at AIAA lunch, 19 Feb 02
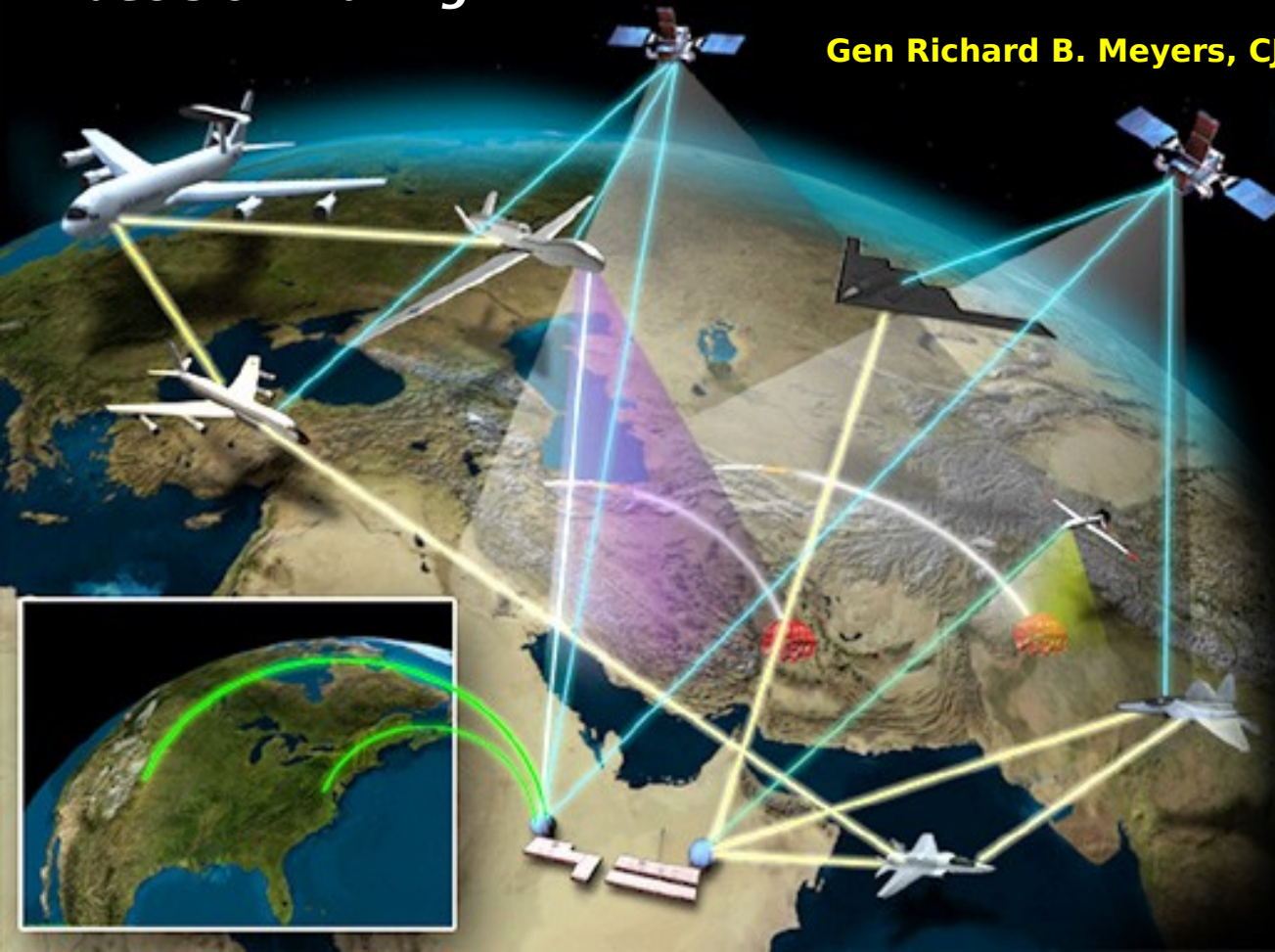
Our Focus:
A Capabilities Based R&D Program

- **Integrated management, fusion, and exploitation of all source ISR assets** in support of Global Vigilance and Focused Awareness

- Ability to **Find, Fix, Target, Track, Engage "At Will"** mobile targets (cyber as well as physical)

- **Distributed rapid planning and C2 M&S** to develop, evaluate, select, execute, and assess joint and coalition **effects-based Courses of Action:** timely & reliable decisions/mission execution

- **Distributed, reconfigurable, and scalable Information Systems** to support integrated civil, commercial, and military (joint/coalition) assets **across the full spectrum of operations** (cyber, surface, air, and space)

- **Global Information Enterprise management & protection** enabling accurate, consistent, timely, assured, **global** information access & dissemination

C2 Capabilities Form Strategic Investment Foundation

Information Directorate S&T Program Thrusts
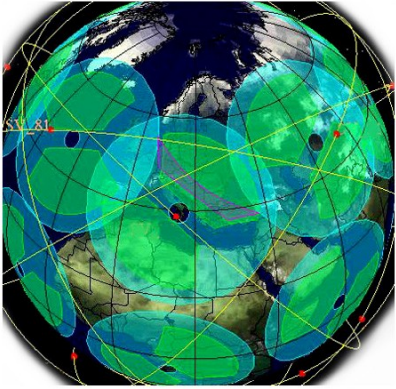
Global Awareness

- *Acquires, exploits, fuses, and reasons over data/information*
- *Provides tailored, consistent, superior situational knowledge*
- *Sufficient precision to enable the decision process at all levels of command*

Dynamic Planning & Execution

- *Rapidly exploits superior, consistent knowledge of the battlespace*
- *Faster, better informed, and more accurate decisions in complex uncertain environments - Air, Space, Surface, Cyber*
- *Shape and control the pace and phasing of engagements*

Global Information Enterprise

- *Moves, processes, manages, and protects information supporting GA and DP&E throughout the global information grid*
- *Multiple military and commercial transmission media*

AFRL/IF Focus Areas

Information Exploitation

Information Fusion & Understanding

Information Management

Advanced Computing Architectures

Cyber Operations

Connectivity

Command & Control

Information Exploitation

Information Exploitation involves the estimation and prediction of signal/feature states on the basis of pixel/signal level data association and characterization, together with the estimation and prediction of entity states on the basis of observation-to-track association, continuous state estimation (e.g. kinematics) and discrete state estimation (e.g. target type and ID)

- **Electronic Intelligence (ELINT)**

- **Communications Intelligence (COMINT)**
  - **Special Signals**

- **Audio & Speech Processing**

- **Imagery Intelligence (IMINT)**

- **VIDEO & Imagery Exploitation**

- **Measurement & Signatures Intelligence (MASINT)**

- **Laser Intelligence (LASINT)**

Audio & Speech Processing
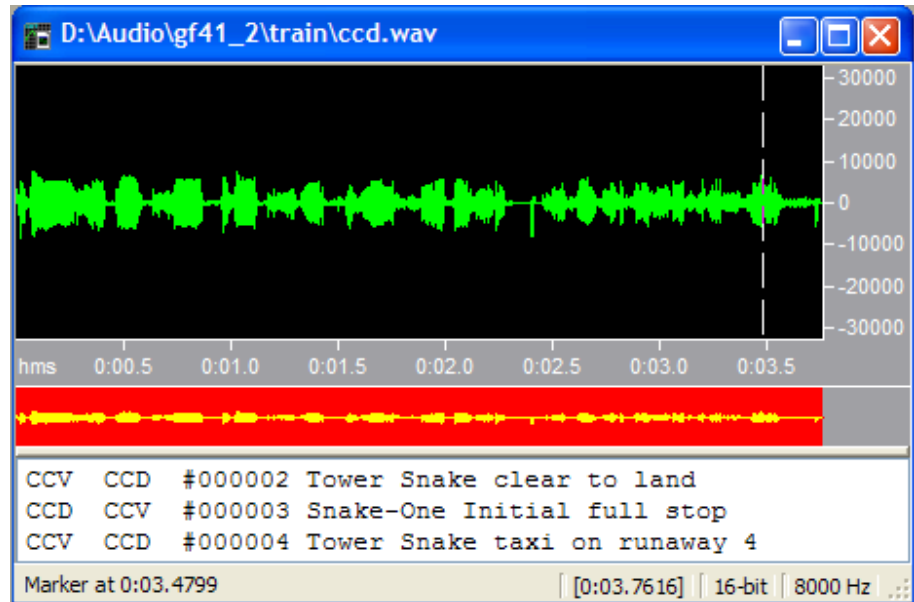## Forensic Automatic Speaker Recognition

Objective: Develop toolkit to aid the FBI in Forensic Audio Casework.

Capabilities
- **Automatic Speaker Verification**
- **Speaker Labeling**
- **Transcription Capabilities**
- **Statistics Function**
- **Blind Channel Estimation and Normalization**
- **Noise Removal**
- **Time-Frequency Displays**

History
- **Began as Research in 1998**
- **Delivered 1st Prototype in 1999**
- **In use today**


```
D:\Audio\gf41_2\train\ccd.wav
```

CCV   CCD   #000002 Tower Snake clear to land
CCD   CCV   #000003 Snake-One Initial full stop
CCV   CCD   #000004 Tower Snake taxi on runaway 4

Marker at 0:03.4799   [0:03.7616] 16-bit 8000 Hz

New Features for FASR
Developing a Proficiency Toolkit to aid audio examiners in enhancing their skills and evaluating their proficiency in human speaker verification.

Information Fusion & Understanding

Information Fusion is defined as the process of combining information (in the broadest sense) to estimate or predict the state of some aspect of the universe. The process is characterized by continuous refinement of its estimates and assessments, and by evaluation of the need for additional sources, or modification of the process itself, to achieve improved results.

- **Multi-INT Fusion**

- **All Levels of Fusion**

- **Predictive Battlespace Awareness**

- **Intelligent Systems Technology**
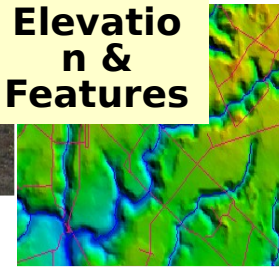
Fusion Problem

What the commanders get...

- Large Number of Uncorrelated Reports

- Data Overload - 100s to 1000s of reports per minute

- Unregistered, soda straw sensor and Wide Area Surveillance observations

SIGINT

Elevation & Features

Weather

HUMINT

IMINT

MTI

What the commanders want...

- **Actionable Information**

  - **All-source Picture of the Battlespace to Provide Real-time Situational Awareness**

  - **Indications and Warnings**

  - **Situational Based ID, Location, Intent, and Threat (1000s of targets)**

Information Fusion Technologies

Genetic Algorithm

Fitness

Optimization Loop

Enemy COA genotype
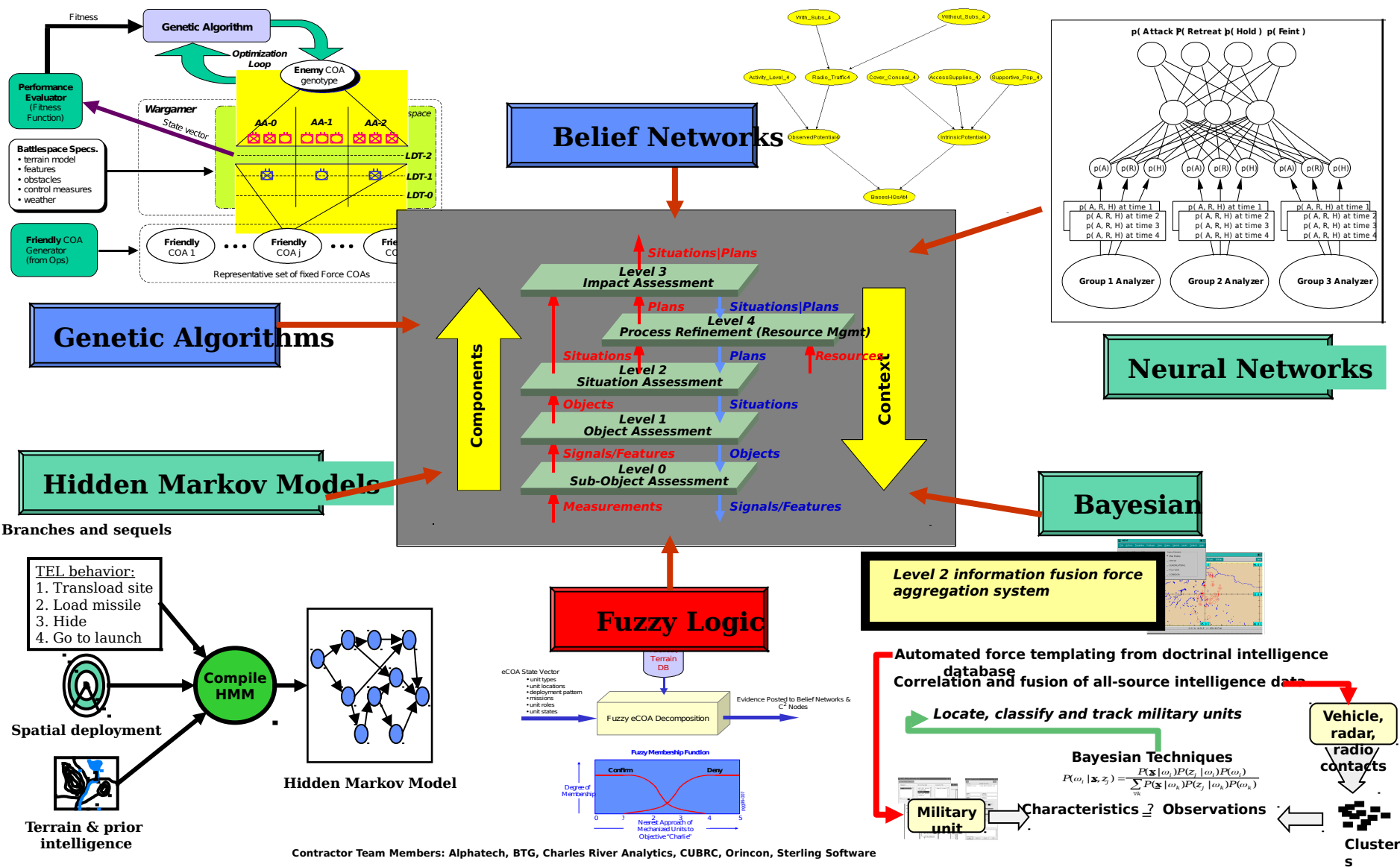
Performance Evaluator (Fitness Function)

Wargamer
State vector

Battlespace Specs.
• terrain model
• features
• obstacles
• control measures
• weather

AA-0 AA-1 AA-2

LDT-2
LDT-1
LDT-0

Friendly COA Generator (from Ops)

Friendly COA 1 ... Friendly COA j ... Friendly COA

Representative set of fixed Force COAs

Genetic Algorithms

Hidden Markov Models

Branches and sequels

TEL behavior:
1. Transload site
2. Load missile
3. Hide
4. Go to launch

Compile HMM

Spatial deployment

Hidden Markov Model

Terrain & prior intelligence

Belief Networks

Components

Context

Situations|Plans

**Level 3
Impact Assessment**

Plans   *Situations|Plans*

**Level 4
Process Refinement (Resource Mgmt)**

Situations   *Plans*   *Resources*

**Level 2
Situation Assessment**

Objects   *Situations*

**Level 1
Object Assessment**

Signals/Features   *Objects*

**Level 0
Sub-Object Assessment*

Measurements   *Signals/Features*

Fuzzy Logic

Terrain DB

eCOA State Vector
• unit types
• unit locations
• deployment pattern
• missions
• unit roles
• unit states

Fuzzy eCOA Decomposition

Evidence Posted to Belief Networks & C² Nodes

Fuzzy Membership Function

Confirm   Deny

Degree of Membership

Nearest Approach of Mechanized Units to Objective "Charlie"

With_Subs_4   Without_Subs_4

Activity_Level_4   Radio_Traffic4   Cover_Conceal_4   AccessSupplies_4   Supportive_Pop_4

ObservedPotential4   IntrinsicPotential4

BasesHQsAt4

p(Attack) P(Retreat) p(Hold) p(Feint)

p(A) p(R) p(H)   p(A) p(R) p(H)   p(A) p(R) p(H)

p(A, R, H) at time 1
p(A, R, H) at time 2
p(A, R, H) at time 3
p(A, R, H) at time 4

p(A, R, H) at time 1
p(A, R, H) at time 2
p(A, R, H) at time 3
p(A, R, H) at time 4

p(A, R, H) at time 1
p(A, R, H) at time 2
p(A, R, H) at time 3
p(A, R, H) at time 4

Group 1 Analyzer   Group 2 Analyzer   Group 3 Analyzer

Neural Networks

Bayesian

Level 2 information fusion force aggregation system

Automated force templating from doctrinal intelligence database

Correlation and fusion of all-source intelligence data

Locate, classify and track military units

Bayesian Techniques

$$P(\omega_i \mid \mathbf{x}, z_j) = \frac{P(\mathbf{x} \mid \omega_i) P(z_j \mid \omega_i) P(\omega_i)}{\sum_{\forall k} P(\mathbf{x} \mid \omega_k) P(z_j \mid \omega_k) P(\omega_k)}$$

Vehicle, radar, radio contacts

Military unit

Characteristics $\stackrel{?}{=}$ **Observations**

Clusters

Contractor Team Members: Alphatech, BTG, Charles River Analytics, CUBRC, Orincon, Sterling Software

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Information Management

Information management is the harnessing of the information resources and capabilities of an organization in order to accomplish its objectives. The challenge of IM in a military context is to achieve the responsiveness and flexibility of the WWW with the control and predictability of traditional C2 IMS.

- **Joint BattleSpace Infosphere**

- **Intelligent Information Distribution**

  - **Semantic Content**

  - **Decision Utility**

  - **Access Policy**

- **Information Quality of Service**

- **Infospherics – S&T of very large-scale, complex information systems design**

AFRL JBI Vision
Delivering Decision-Quality Information

Tomorrow

Horizontal App	Horizontal App
Application	**Application**

Horizontal App	Horizontal App	Horizontal App
Application	Application	Application

iCS 0.3.3.0	¥Publish - Subscribe ¥Query ¥Transform (Fuselets) ¥Control

Physical Network (Communications)

JBI Platform Core Services
- **Publish - Subscribe**
- **Query**
- **Transform (Fuselets)**
- **Control**

Physical Network (Communications)

1999 AF SAB: … a system of systems that integrates, aggregates, and distributes information to users at all echelons, …

Today

Vertical App	Vertical App
Application	**Application**
Presentation	**Presentation**
Session	**Session**
Transport	**Transport**

$ $

Physical Network

- **Highly Scaleable & Flexible**
- **Secure (DoD) with high availability**
- **Policy-directed access control & prioritization**
- **Tailored information environment**
- **Standards-based: Internet / Semantic Web**
  - **Readily exploits new technology**
  - **Low cost of entry & total cost of ownership**
  - **Interchangeable (or interoperable)**

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Advanced Computing Architectures

The set of data types, operations, and features of each level of computer design is called its architecture. The architecture deals with those aspects that are visible to the user of that level. (Tannenbaum)
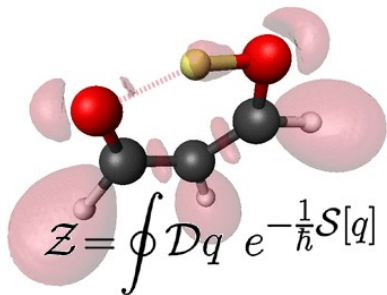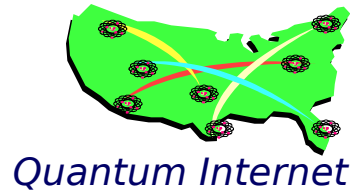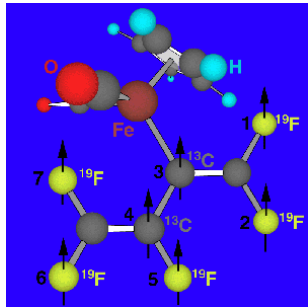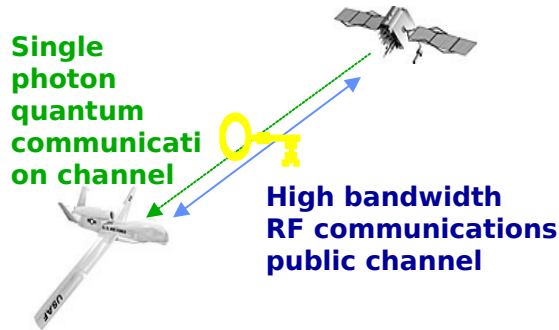
- **Fundamental Models of Computation**

- **Engineering Techniques for Design of Computing Systems**
  - **hardware & software**
  - **application of theory to design**
    - **High Performance Computing for C2 (Traditional and Cluster HPCs)**
    - **Biomolecular Computing**
    - **Nano-Computing**
    - **Quantum Information Science**
    - **Other**
      - **Cellular automata, Grid computing, Autonomic Computing et**

Quantum Information Science

Notional aircraft-to-satellite QKD link

Single photon quantum communication channel

High bandwidth RF communications public channel

Quantum Internet

$$\mathcal{Z} = \oint \mathcal{D}q \; e^{-\frac{1}{\hbar}\mathcal{S}[q]}$$

Entropy Exchange Unit

Qubit Refresh Unit
Code-Teleporter
CAT State Generator
Ancilla Generator

Quantum Memory

Quantum Parallel ALU

Dynamic Quantum Compiler/Scheduler
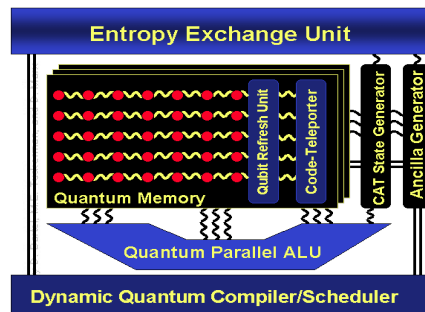
Program Description

- **Develop *revolutionary computing and communication* capability based on quantum information processing to enable:**

    - **Solving previously intractable algorithms**

    - **Ultra-secure communication**

    - **Ultra-precise metrology**

    - **Beyond Shannon channel capacity**

    - **Distributed signal processing**

Cyber Operations

- **Cyber Operations** is that part of Information Warfare that includes the following:
  - **Information Assurance** comprises those measures to protect and defend information and information systems by ensuring their availability, integrity, authenticity, confidentiality, and non-repudiation.
  - **Computer Network Defense** is actions taken to plan and direct responses to unauthorized activity in defense of AF information systems and computer networks.
  - **Computer Network Attack** operations are conducted using information systems to disrupt, deny, degrade, or destroy information resident in computers and computer networks, or the computers and networks themselves.
  - **Computer Network Exploitation** operations are Intelligence, Surveillance, and Reconnaissance (ISR) functions in cyberspace that result in the ability to gather information about the adversary, their intentions, and their capabilities.
  - **Assured Infrastructure Support** capabilities to support and assure the survivability of CNA, CND, CNE operations
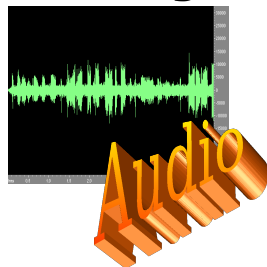
Digital Data Embedding/Hiding

Warning! Image contains hidden data

Classification:
Unclassified

Warning! Image has been modified
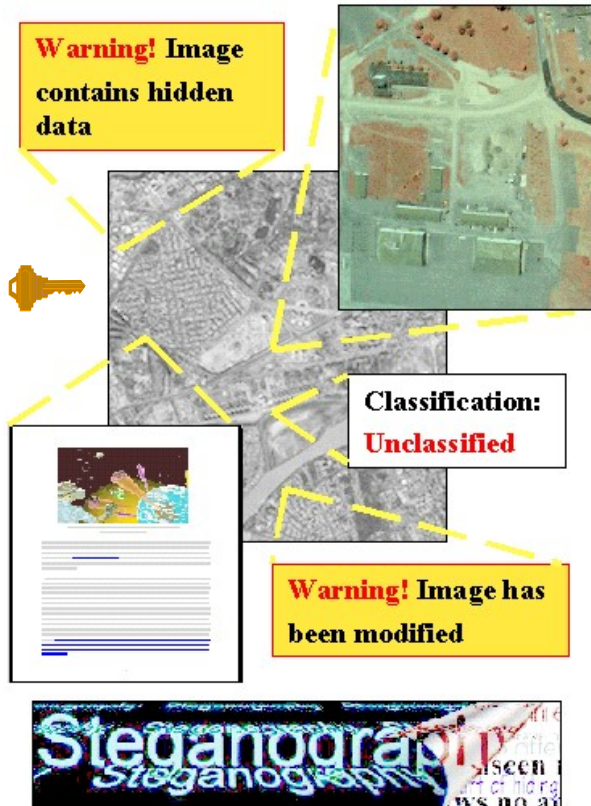
Data Hiding/Embedding

Steganography

Watermarking

Steganalysis

Technology Area Payoff

- **Information Assurance**
  - **data & source authentication**
  - **tamper detection & data recovery**
  - **automatic data dissemination through guards; classification & license marking**
  - **detection & identification of adversary steganographic activity & extraction of hidden data**
  - **tracing sources of data leaks**
  - **minimize data loss (corrupt data pointers; invalid data headers)**
- **Information Enhancement**
  - **embedded auxiliary information (images, documents, overlays, audio, links, etc.)**
  - **multi-level data release to coalition forces; key-based access**
  - **covert communication**
  - **maximize throughput of**

Connectivity

High Capacity Communications
Integrated RF Optical systems (e.g. Antenna apertures, Lightwave ICs)
New Waveforms (more bits/Hz, resilient, LPI)
All optical switching & routing (no O-E-O conversion)
Spectrum Utilization/Efficiency distributed real time spectrum sensing,
analysis, & allocation & allocation
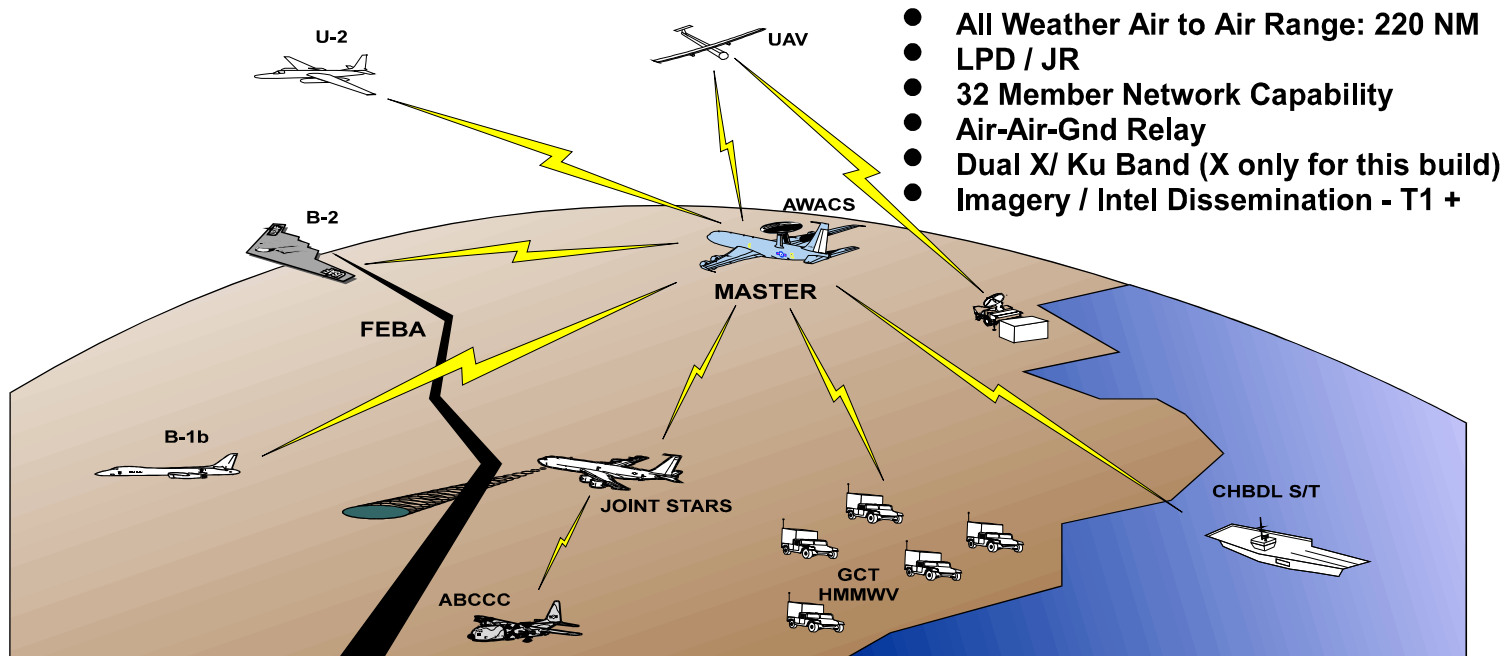
C2ISR Networking
Resilient Protocols for dynamic/disadvantaged environments
Multiple/diverse media (kb to Gb) Access and Control
Adaptive end to end QoS for variable bit rate connectivity
Mobile/Ad hoc – hand-offs, security, route propagation scalability
Embedded Universal Gateways & Integration with Legacy Services

Enterprise Management & Control
Across AF, Joint, and Coalition Domains Space, Airborne, Ground, Sea
Wireless Information Assurance
Policy based QoS with dynamic bandwidth allocation

High Capacity Information Connectivity for Aerospace Platforms

- All Weather Air to Air Range: 220 NM
- LPD / JR
- 32 Member Network Capability
- Air-Air-Gnd Relay
- Dual X/ Ku Band (X only for this build)
- Imagery / Intel Dissemination - T1 +

Diagram labels: U-2, UAV, B-2, AWACS, MASTER, FEBA, B-1b, JOINT STARS, ABCCC, GCT HMMWV, CHBDL S/T

- **Technology Challenge:**
  - **Provide 1-2 Gbps data transfer capacity (4X improvement)**
    - **- Little or no reduction in link margin**
    - **- Implementation of Turbo codes at 1Gbps**
    - **- New Parallel Modem Architecture on FPGA**
    - **- Limited reduction of AJ and LPI capability**
    - **- Advanced Modulation and waveforms**

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Command & Control

Command & Control **is the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. Also called C2. (JP 0-2)**

- **Effects Based Operations**
- **Adversarial Modeling**
- **Battlefield Simulation**
- **C2 Decision Support**

Effects-Based Operations (EBO)

Cyber Attack

USAF has practiced EBO at the tactical level of war
Need: EBO analysis & assessment at all levels

Air Attack

Disclosure *Denial Of Service*

Espionage *Destruction*

Direct Effects

Denial Of Service

Infrastructure

Military Forces and Command Centers

Indirect Effects

Leadership

Key Information Capabilities

- **Strategy development for creating effects-based COA options**
- **Modeling enemy as a system (centers of gravity - cyber and physical)**
- **Wargaming with friendly & adversarial COA analysis with cost of alternatives**
- **Linking & integrating theater-wide effects**
- **Dynamic tasking, including ISR**
- **Directing execution through dynamic, real-time C2**
- **Measuring achievement of commander's intent through campaign assessment**

Tactical
Disabled Enemy Electrical Bridges Grid Destroyed

Operational
Fielded Forces Paralyzed

Strategic
Enemy Strategy Defeated

Effect ←→ Mechanism

The Changing Landscape of Warfare

Kinetic Warfare

Characteristics:
Air and Space Vehicles: UCAVs
Flight Medium: Air & Space
Weapons: Missiles & Bombs
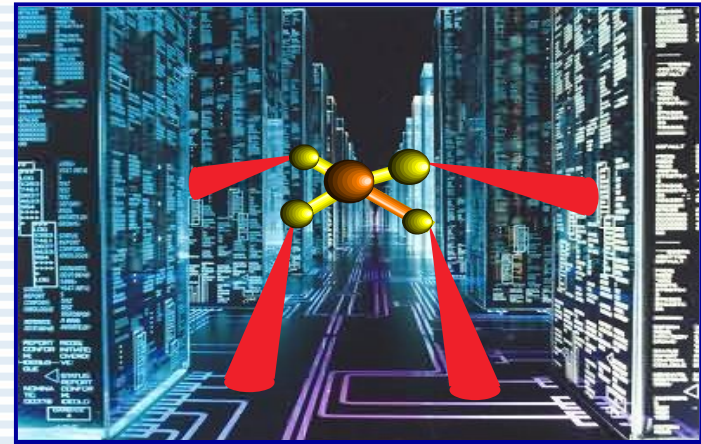Desired "Effect": Destroy Target
Control: Air/Space/Ground movement
Low Probability of Intercept: Stealth (Physical)
Low Probability of Detection: Terrain Masking
Homebase: Predetermined Airfield
Logistics: Heavy, Continual

Cyber Warfare

Characteristics:
Cyberspace Vehicles: Info-Crafts
Flight Medium: Cyberspace
Weapons: Virus, Worm
Desired "Effect": Destroy, Degrade, Co-opt
Control: Network Links that support enemy
  Air/Space/Ground movement
Low Probability of Intercept : Stealth (Software)
Low Probability of Detection : Network Masking
Homebase: Any Cyberspace Portal
Logistics: Light, Infrequent (software)
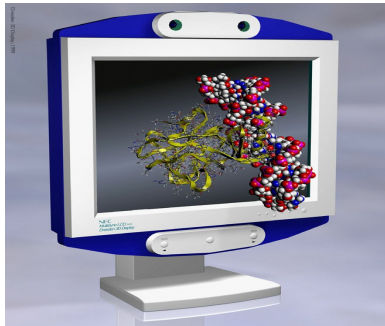
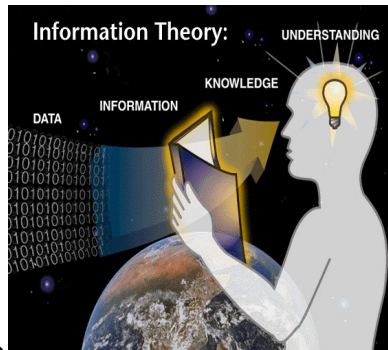# Net result is the same: *IMPEDE THE ENEMY*

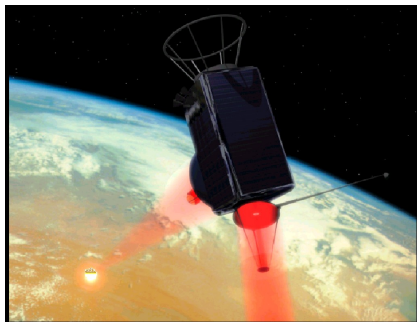# The Changing Landscape of Research
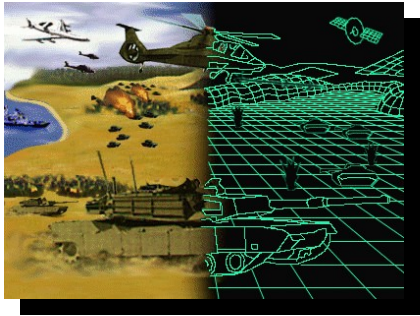
Virtual Worlds

Virtual Presence

Advanced Computing

Cognitive Sciences

IT in Space

Cyber World

BioTechnology
- Bio-inspired Architectures
- *Bacteriorhodopsin* Memory
- BioComputing

- **NanoTechnology**
  - MEPSI PICOSAT Inspector
  - Nanotechnology

- **Quantum Technology**
  - Quantum Information Systems
  - Quantum Communications

"The first essential of air power is pre-eminence in research"

– *General H.H. Arnold, 1944*

http://www.if.afrl.af.mil/tech/tech_main.html